U.S. DEPARTMENT OF COMMERCE
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PB-257 292

MEATPACKING WASTEWATER TREATMENT BY SPRAY RUNOFF IRRIGATION

Pacific Northwest Environmental
Research Laboratory

May 1975

260003

PB 257 292

U.S. ENVIRONMENTAL PROTECTION AGENCY

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BY SPRAY RUNOFF IRRIGATION

By

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PNERL Working Paper
Number 15

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PACIFIC NORTHWEST ENVIRONMENTAL RESEARCH LABORATORY
An Associate Laboratory of
National Environmental Research Center—Corvallis

BIBLIOGRAPHIC DATA SHEET	1. Report No. Working Paper-15	2.	3. Recipient's Accession No. PB-257 292
4. Title and Subtitle Meatpacking Wastewater Treatment by Spray Runoff Irrigation			5. Report Date May 75 6.
7. Author(s) Jack L. Witherow, and Mickey L. Rowe			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Pacific Northwest Environmental Research Lab. Corvallis, Oregon Industrial Wastes Branch			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*Industrial waste treatment,
*Irrigation,
*Runoff,
*Meat,
*Food processing,

Packaging,
Slopes,
Vegetation,
Waste water reuse,
Odors,
Insects,
Drift,
Freezing,
Precipitation(meteorology).

17b. Identifiers/Open-Ended Terms

*Sewage irrigation,
Overland flow.

17c. COSATI Field Group 13 B 2 C 6 H

18. Availability Statement National Technical Information Service Springfield, Virginia 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 37p
	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.00/2.25

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

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MEATPACKING WASTEWATER TREATMENT BY SPRAY RUNOFF IRRIGATION

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Jack L. Witherow* and Mickey L. Rowe**

INTRODUCTION

Spray runoff irrigation is a treatment process in which wastewater is applied to sloping, plant covered land. The process yields a treated effluent which is collected on the toe of the slope for discharge. The process is also referred to as an overland flow system or a living filter. Utilization of the system is dependent upon such variables as available land, soil type, topography, climate, location, and wastewater characteristics. Vegetable processing plants using this process require a land area of about 100 acres per mgd (1). Clay type soils are needed to control infiltration and to promote runoff. Also necessary is a surface with a 2-6% slope which is smooth enough to prevent pooling or channelization of flow.

While spray runoff irrigation has many advantages, there are inherent problems to be overcome. Solids and grease in the waste water may build up deposits under the spray pattern and result in anaerobic conditions. The potential for odors, insects, and aerosol drift restricts locating this treatment process near residential areas. Precipitation and freezing temperatures limit wastewater application; however, this can be overcome through use of storage facilities.

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This report presents a study on a pilot scale spray runoff irrigation system. The objectives of the study were: (1) to determine if the system would sufficiently treat meatpacking wastewaters to meet national discharge limitations, (2) to ascertain whether a goal of 80 percent removal of both total nitrogen and phosphorus could be achieved to meet future environmental needs, and (3) to establish the economic feasibility of the system.

EXPERIMENTAL DESIGN

A previous study (2) had shown that a meatpacking waste which had received treatment in an anaerobic lagoon could be treated by spray runoff irrigation to meet average discharge limits for 1977. (At the time of the study maximum daily limits had not been proposed.) However, use of an anaerobic lagoon prior to spray irrigation can create a nuisance. Protein and sulfates in the wastewater will be reduced in the lagoon to ammonia and hydrogen sulfide, respectively. These will be released to the atmosphere by the spraying action. This potential problem may be eliminated and the system design may be simplified by using raw meatpacking wastewater in the irrigation process.

Spray runoff irrigation of meatpacking wastewater was studied for six months in a pilot plant located at the W. E. Reeves Packinghouse in Ada, Oklahoma (Figure 1). Application of the waste began in January and ended in June allowing evaluation under both cold and warm weather conditions. The raw wastewater was diverted from a manhole several minutes each hour to obtain the limited quantity needed and to composite a wastewater representative of the plants daily flow. The wastewater passed through a hydrosieve with 0.020-inch slot openings and was stored in a 2100 gallon tank (Figure 2). The hydrosieve was used for removal of solids which would clog the spray nozzles. The storage tank was used to equalize flow and to give a positive pressure on the pump inlet. The storage tank was aerated to prevent anaerobic conditions and solid-liquid separation.

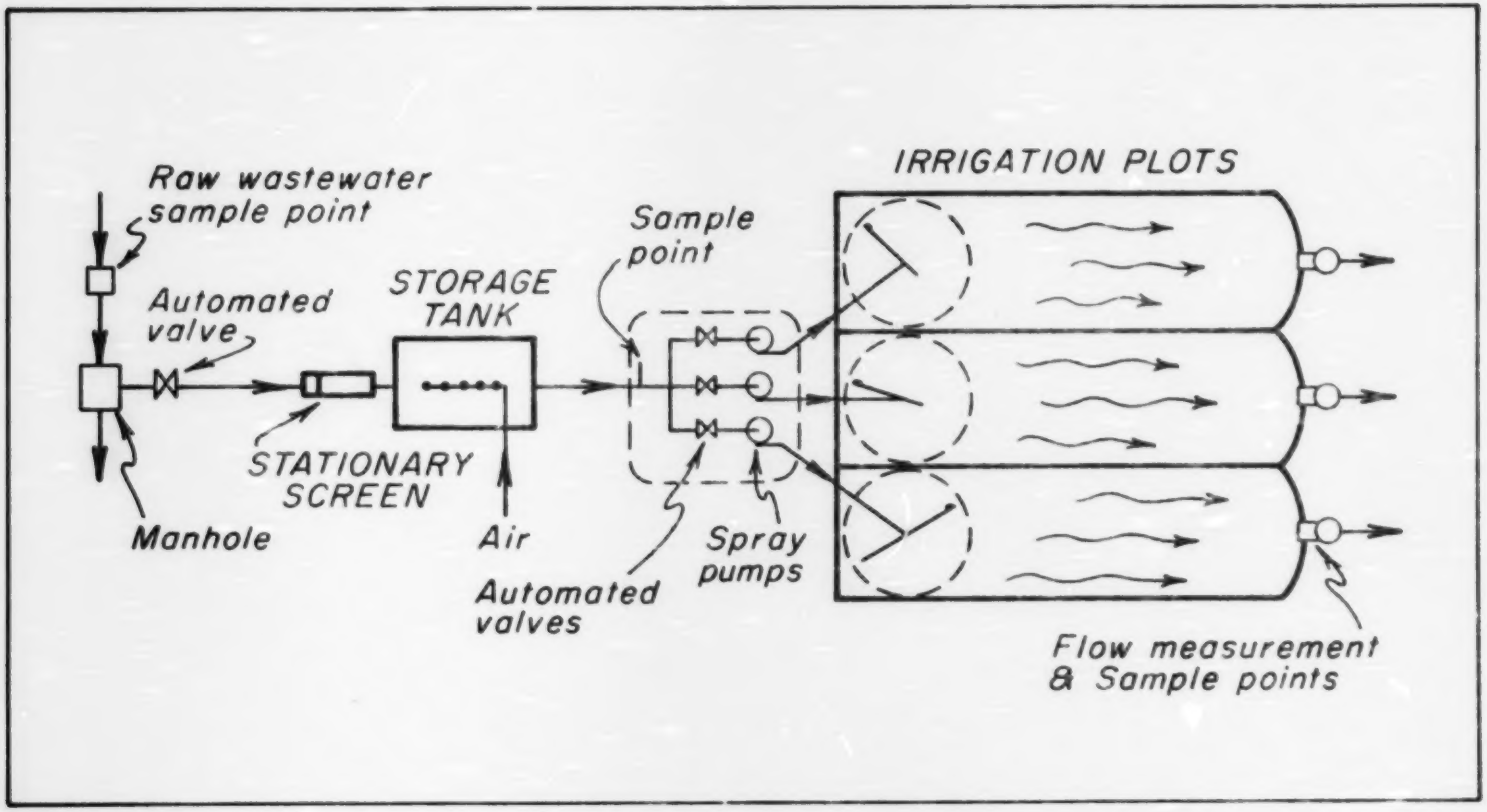

FIGURE I. SPRAY RUNOFF IRRIGATION PILOT PLANT

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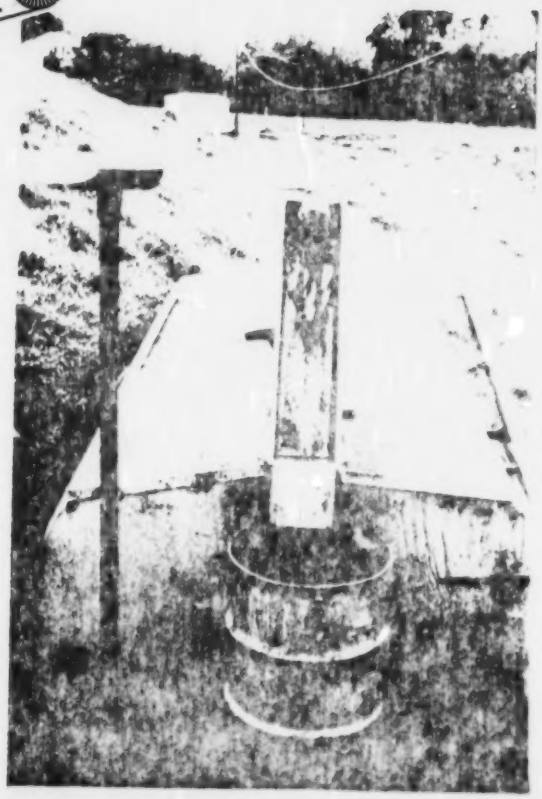

Figure 2. Hydrosieve & Aerated Storage Tank

Figure 3. Distribution System & Irrigation Plots

Each of the three 0.1 acre irrigation plots were 33 ft. by 115 ft. The site for the plots had 3 to 12 inches of soil over conglomerate rock. A clay loam soil was added to form a smooth surface with a 6 percent slope. The increased soil depth ranged from 1 to 4 feet. A native bermuda grass was grown on the plots to provide a deep mat for bacterial growth and errosion contrul. A berm was placed on the upper end of the plots to divert rainfall runoff. Aluminum stripping was placed around each plot to direct the spray runoff through an outlet structure where flow was measured by a tripping bucket and counter arrangement.

Because revolving irrigation guns were not successful on these small plots, revolving booms with nozzles at the ends were used to provide even distribution of flow across the plot (Figure 3). The radius of the spray pattern was adjusted to remain within the 33 ft. width. Health hazards from aerosol drift due to high pressure application have caused Tarquin, et al., (3) to also use low pressure booms. Constant speed positive displacement pumps were used to apply and measure the flow to the three soil plots. These pumps were operated up to 55 hrs per week during the regular hours of plant operation. The flow per minute for each plot was measured by catching the nozzle discharge, and application rates were established by controlling the time each pump was operated per day.

Weekly samples were taken of the raw wastewater, of the screened and aerated wastewater applied to the soil plots and of the effluent from each plot. Automatic composite samples were taken of the raw wastewater and wastewater applied to the plots. Grab samples were taken of the three plot effluents. Previous experience with this process had shown that grab samples of these effluents were satisfactory (4). The automatic samplers were activated to take four samples per hour during the slaughtering and/or processing operations in the packinghouse.

Samples were time composited in iced containers. Collected samples were stored at 4°C in the laboratory.

The weekly samples were analyzed for five day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), pH, total solids (TS), total volatile solids (TVS), suspended solids (TSS), ammonia (NH_3-N), nitrate plus nitrite (NO_2+NO_3-N), total Kjeldahl nitrogen (TKN) and total phosphate (T-P). In situ measurements were made for temperature and dissolved oxygen (DO) during sample collection. Once a month specially collected samples were analyzed for oil and grease (FOG), settleable solids and fecal coliforms.

All analyses were made in accord with EPA Methods for Chemical Analysis of Water and Wastes, 1971. The chemical analyses were subjected to quality control procedures. Duplicate analyses were run on 10% or more of the samples. The sum of the squared differences was plotted on a quality control chart for each analysis. When the difference was outside of the established boundaries, the samples were analyzed again. Standards were also run on most analyses. In the middle of the study period two sets of unknown reference samples were analyzed for BOD_5, COD, NH_3-N, PO_4-P, TKN and T-P. All results were within one standard deviation of the true value.

Sampling Accuracy

Solids-laden waste streams are difficult to sample. For this reason, an automatic sampler which dipped a container below the surface was selected for sampling the raw wastewater. It was hoped this sampler would eliminate the plugging and straining problems caused by small pumps and small diameter lines used in most samplers. The sampling location was designed to create turbulance for solids mixing and elimination of solids deposits. Harris and Keffer (5) have compared types of

automatic samples and found vacuum samplers with high intake velocities obtain higher concentrations of parameters influenced by solids. On two occasions, dual samples were taken--one by the automatic dip sampler; the other by an automatic vacuum actuated sampler. All samples were time composited. The routine analysis on both samples showed the vacuum samples to be about 20% higher for BOD, COD, TS, TVS, TSS and about 20% lower for TKN than the dip samples. The automatic dip sampler apparently missed 20% of the solids in the waste stream.

An automatic sampler containing a centrifugal pump was used for sampling the screened and stored wastewater. The sampler was installed on the intake line to the spray pumps. To obtain representative solids levels, samples were only collected when the spray pumps were operating. To obtain a sample for comparison, an open container was placed under the spray pattern on one of the plots. Both samples were time composited. A comparison of the analyses revealed the pumped sample to be about 25% lower in COD, TS, TVS, and TSS, but about 75% higher in NH_3-N than the waste collected as it fell to the soil plot. Apparently the automatic sampler did not obtain all solids that had passed through the 0.02 inch screen openings and the spraying action scrubbed a significant amount of ammonia from the wastewater.

EXPERIMENTAL RESULTS

Screening and Storage

The passing of the raw wastewater through a 0.020-inch slot opening in a tangential screen and the aerated storage in a 2100 gallon tank resulted in significant reduction in the waste strength. The concentrations and removals shown in Table 1 are based on mean values. The concentrations of BOD_5, COD and TSS may be 20 to 25% low because of automated raw waste sampling. Additional statistical data on the influent and effluent are in the appendix.

Table 1. Effects of Screening and Storage

Items	Influent (mg/l)	Effluent (mg/l)	Removal (%)
BOD_5	634	374	41
COD	1675	936	44
TSS	499	219	57
FOG	139	67	52

The screen served the intended purpose of removing the large solids and preventing plugging of the spray nozzles. Screens offer the advantage of removing solids (bone, hair, toenails and plastics) that would not be treated by the irrigation process. The pilot scale operation made the disposal of the screen solids a minor task. In a large operation, mechanized solids handling equipment would be needed.

Part of the raw waste flow was diverted from the packinghouse sewer a few minutes each hour by means of an automated valve. With this intermittent diversion, the storage tank was necessary for continual application to the spray plots. Air was introduced through a header at the bottom of the tank to mix the contents and to maintain aerobic conditions. The dissolved oxygen in the tank liquid averaged 0.8 mg/l. The liquid detention time in the tank was calculated as averaging less

than six hours, but liquid remained in the tank over night. The tank was drained and flushed weekly to remove minor sludge deposits. Reduction of protein in these deposits is suspected as the cause of the average increase of 18 mg/l of NH_3-N. In a full-scale operation, increase in ammonia could be minimized by standard wet well designs.

Loading on the Plots

The flow applications were initially set to increase phosphorus removal. The concept was to increase the liquid detention by applying the flow intermittently. The pumps and nozzles would deliver 0.07 inches/hour, but the flows to plots 5, 6, and 7, were only applied 40, 30, and 20 minutes/hour, respectively. After two months of operation it was concluded that this on-off application was not successful in increasing phosphorus removal. The emphasis was shifted to minimizing NH_3-N and NO_2+NO_3-N in the discharge. Minimum concentrations of these parameters were being obtained on plot 5. To bracket the loading on this plot the application on plot 7 was increased to 50 minutes per hour in mid-March. In mid-May, a period of high evaporation eliminated the surface discharges from plots 5 and 6. To gain additional information the application to plot 6 was increased by running the pump continually 10 hours per day. The average flows applied to plots 5, 6, and 7 during study are given in Table No. 2.

Table 2. Loading on Irrigation Plots
(mean values)

Items	Units	Plot 5	Plot 6_a	Plot 6_b	Plot 7_a	Plot 7_b
Flow	gal/acre/day	10,490	9,050	16,610	6,560	14,800
BOD_5	lb/acre/day	32.7	29.5	47.7	21.8	45.0
COD	lb/acre/day	79.3	73.2	97.1	52.8	106.2
TSS	lb/acre/day	17.8	14.3	30.5	8.7	28.0
NH_3-N	lb/acre/day	2.8	2.1	5.8	1.1	4.9
T-N	lb/acre/day	9.4	8.2	14.6	5.0	14.2
T-P	lb/acre/day	0.6	0.5	0.9	0.5	0.7
(Operation in weeks)		21	15	6	8	14

Since the wastewater was applied to the three plots, the organic and nutrient loadings are directly proportional to the hydraulic loadings. The loading of BOD_5, COD, TSS, NH_3-N, T-N and T-P in lb/acre/ day are shown in Table 2. The nitrogen loading is important because a few states put limitations on this nutrient to protect ground water supplies. The wastewater had a ratio of BOD_5/N/P of 100/30/2, which is satisfactory for biological treatment processes. Additional data on loadings and concentrations are in the Appendix.

Discharge from the Plots

Table 3. Discharge from Irrigation Plots
(mean values)

Items	Units	Plot 5	Plot 6_a	Plot 6_b	Plot 7_a	Plot 7_b
Flow	gal/acre/day	2510.	3190.	1120.	1150.	4570.
BOD_5	lb/acre/day	0.41	0.38	0.06	0.06	0.75
COD	lb/acre/day	4.21	5.09	1.06	0.94	5.25
TSS	lb/acre/day	1.04	0.73	0.21	0.15	1.12
NH_3-N	lb/acre/day	0.04	0.02	0.00	0.00	0.04
T-N	lb/acre/day	0.35	0.53	0.03	0.15	0.14
T-P	lb/acre/day	0.17	0.23	0.07	0.06	0.21
Temp.	°C	17.2	15.4	27.4	13.8	22.9
BOD_5	mg/l	10.0	5.8	5.2	6.0	10.1
COD	mg/l	123.	107.	103.	103.	132.
TVS	mg/l	270.	233.	179	271.	215.
TSS	mg/l	25.	23.	17.	17.	26.
NH_3-N	mg/l	1.2	0.5	0.0	0.6	0.5
T-P	mg/l	6.7	5.9	6.9	6.5	6.4

Removal efficiencies based on both concentrations and pounds of pollutants were calculated from the data in Tables 2 and 3 and the Appendix. Removal efficiencies were 90% or greater for all plots; exceptions were pounds of phosphorus and mg/l of COD, TVS, and T-P. The percentages are not presented because, with one exception, they did not show any meaningful differences among plots. The exception was the pounds of phosphorus removed. This difference was the result of increased water loss during warm weather. Removal of phosphorus on the basis of

Concentration was similar among plots and less than ten percent. However, average flow losses across the plots varied from 65 to 97 percent of that applied.

The average conditions given in Table 3 show all the plots to discharge low concentrations of pollutants and show minor changes in concentration among plots. The variation in hydraulic and organic loading conditions tested had little effect on removals. Two factors which mask the differences that occurred were the effects of the weather and the averaging of extremes. The weather caused these extreme conditions and was the singularly most significant factor in affecting discharge loads under the test conditions.

The loadings and weather conditions of plots 6_b and 7_a were the most widely different; yet the discharges were remarkably similar. There was no meaningful difference in removal efficiencies based on pound of pollutants and, except for TVS, the concentration of the two discharges appeared identical. A statistical test showed no significant difference between the TVS means. Thus, a loading of 16,600 gallons/acre/day (gpad) in the summer and a loading of 6,500 gpad in the winter resulted in the same average volume and mass of pollutants in the discharges. The data on Plot 6_b was collected in January, February, and March, and the data on Plot 7_a was collected in May and June. The respective pan evaporation for these two periods averages 3.5 in/month and 9.0 in/month.

A comparison of effluents from plot 6 for a period of six weeks in April and May at a hydraulic loading of 9000 gpad with the following six weeks in May and June at a hydraulic loading of 16,500 gpad showed little or no difference in concentration of pollutants. Almost doubling the hydraulic loading did not result in a noticeable decrease in removal based on concentration during these two warm periods.

Waste load discharges can best be controlled by matching hydraulic loadings with weather conditions to limit discharge volumes.

Rainfall Effects

Rainfall on wastewater irrigation plots can significantly increase the waste loads discharged in the runoff. Rainfall increases the volume of runoff and may increase the concentration of some pollutants in the discharge. Law, et al (4) evaluated the effect of rainfall by continuous measurement of electrical conductivity. They found that rainfall of 0.1 inch or less did not contribute enough volume to alter the composition of the runoff contributed by the applied wastewater. Rainfall events of 0.1 to 2.0 inches had a marked effect by steadily decreasing the conductivity with increasing amounts of rainfall. Rainfall events greater than 2.0 inches caused little additional reduction in conductivity. This information does not include runoff flow measurements and waste loads cannot be calculated. The information does indicate that waste load discharged are increased by rainfall events greater than 2.0 inches.

During this investigation, routine sampling occurred on three days when rainfall was part of the grab sample of the effluent. The rainfall intensity at the time of sampling was not measured, but the rainfalls ranged from 0.7 to 1.5 inches/day. In two of these three events the runoff volume exceeded that of the applied wastewaters. In these two events the pounds of phosphorus discharged were greater than that applied and the suspended solids discharged exceeded the maximum day limit in the Best Available Treatment (BAT) standards. In one event the BOD_5 discharged also exceeded the BAT daily limit. To specifically measure the effects of rainfall, composite samples of the runoff from the plots were taken during five rainfall events, outside of the routine sampling schedule. These samples were analyzed for TS, TVS, TSS and T-P.

Total solids concentrations in the discharge samples taken during rainfall were considerably less than during non-rainfull periods. This is in agreement with the conductivity data reported by Law (4). The over 1500 mg/l difference in TSS between the wastewater and rainfall can account for these decreases by dilution. Total volatile solids and total phosphorus did not differ significantly in concentration; however, suspended solids were usually higher and in one case the concentration was ten times that of the previous sample taken during dry weather. Flow recordings were not taken during these rainfall events and pounds of TSS discharged cannot be computed. During rainfall, the discharge flow is certain to increase over dry weather discharges. During periods when wastewater is applied, rainfalls of greater than 0.7 inches/day can increase waste concentrations as much as ten times average discharge values and maximum daily limits in the BAT standards can be exceeded.

A discharge volume was measured and sampled during a rainstorm when wastewater was not being applied. A rainfall of 0.62 inches was measured at the local weather station. The runoff from the plot was 230 gal/acre. The concentrations of TVS and TSS were 240 mg/l and 11 mg/l, respectively, which were similar to discharge concentrations the next day when wastewater was applied and there was no rainfall. The rainfall runoff from the plot had a TS of 634 mg/l, about half that in the next days sample. Rainfall on the irrigation plots can also result in a waste load discharge between periods when wastewaters are applied.

Effects of Temperature

Water temperature was measured at each sample point at the time samples were collected and minimum and maximum daily air temperatures were obtained from the local weather station. The two sources of heat were the plant's hot water system and the ambient conditions. The ambient conditions, as defined by air temperatures, were dominant and

from January into April usually reduced the wastewater temperature as it passed through the collection and treatment systems. In late April, May and June ambient conditions usually maintained a stable wastewater temperature through these systems.

Because the effect of temperature on biological treatment is well established, the study period was selected to encompass both cold and warm weather conditions. A statistical analysis was made to determine the correlation between effluent temperatures and concentrations of BOD, COD, NH_3-N, NO_2+NO_3-N and T-P for plots 5, 6a and 7b. The analyses were made on effluent concentration rather than on change in concentration or removal efficiencies. These latter items were mainly controlled by the influent concentration, and temperature and influent characteristics are not usually related. The analyses gave no significant correlations between the parameters and temperature except for NO_2+NO_3-N. On both plots 5 and 6a a correlation coefficient of -.71 was obtained. The average temperatures and average NO_2+NO_3-N levels for the three plots show the same negative correlation.

Averages	Plot 6a	Plot 5	Plot 7b
Temp. (°C)	15.8	18.2	25.6
NO_2+NO_3-N (mg/l)	10.8	4.6	0.5

The correlation for Plot 7b was not statistically significant, but the low concentration of NO_2+NO_3-N was meaningful. On the three plots the effluent concentrations of NH_3-N and T-N were related to temperature. After mid-April the effluent temperatures remained above 20°C at which time NH_3-N concentration dropped to zero and remained there throughout the rest of the study period. Total nitrogen concentration dropped significantly at this time and remained below 6.2 mg/l.

Reduction of protein nitrogen to ammonia in the storage tank was affected by temperature. The screened wastewater was held for several hours in a tank prior to spraying on the plots. The concentration of NH_3-N and the temperature had a correlation coefficient of 0.65. Ammonia concentration consistently increased in the tank, but the increases were greatest after mid-April. Other forms of nitrogen did not noticeably change after mid-April in this waste stream applied to the three plots.

Removal of all forms of nitrogen on the soil plots was affected by temperatures. Maximum reduction occurred after water temperature reached 20°C. The apparent causes were: the increased concentration of NH_3-N and its loss to the atmosphere by spraying; a reduction of NO_2+NO_3-N by denitrification, and nitrogen uptake by increased microbial and plant growth. Because of the impermeable rock layer below the soil plots, loss of nitrogen into a ground water supply was not possible.

Temperature had an effect on the discharge volume. The most notable effect was when a surface discharge did not occur on hot days when ambient conditions maintained high water temperatures. The absence of a discharge was noted at 9000 gpad with an influent temperature of 19°C and at 10,500 gpad with an influent temperature of 25°C. However, a discharge continued at 15,000 gpad with effluent temperatures of 30°C. In addition to temperature, wind noticeably influenced the discharge volumes. A prolonged period of freezing temperatures sufficient to stop the discharge because of ice formation did not occur during the study period.

NATIONAL EFFLUENT LIMITATIONS

The effluent limits, for the category "low packinghouse" given in Table 4 are maximum values for an average of daily values within 30 consecutive days or for any one day. All of the treatment systems meet

the Best Practicable Treatment (BPT) limits in Table 4 which must be met by July 1, 1977. Plots 6_b and 7_a meet the Best Available Treatment (BAT) limits in Table 4. The BAT limits must be met by July 1, 1983. In all cases, the BAT limits which were exceeded were maximum day limits. The difference between average discharges and maximum day discharges were ten fold rather than double.

All maximum day values which exceeded the BAT limits in Table 4 occurred on two sample days when heavy rainfall occurred. On March 20, 1974, a rainfall of 0.71 inches was so intense that the flow measuring devices were unable to record all the discharge. On this day, the waste load discharge from all plots exceeded both the BOD_5 and TSS limits. A heavy rainfall did not occur when samples were collected from plots 6_b and 7_a.

All averages calculated for 30 day periods consisted of four or less data points. Except for that period which included March 20, 1974 data these values meet the BAT limits in Table 4. To obtain a better estimate of the mean, the treatment system 30 day values in Table 4 are averages for entire study periods.

Table 4. Comparison of Treated Wastewaters and Effluent Limitations

Treatment Systems	BOD_5 (#/1000# LWK) 30 day	1 day	TSS (#/1000# LWK) 30 day	1 day
Plot 5	.01	.14	.05	.48
Plot 6_a	.02	.19	.06	.34
Plot 6_b	<.01	<.01	<.01	.02
Plot 7_a	<.01	.01	.01	.02
Plot 7_b	.02	.29	.04	.40
Effluent Limitations				
Best Practical Treatment	.17	.34	.24	.48
Best Available Treatment	.04	.08	.06	.12

In addition to the parameters in Table 4, there are limits on oil and grease, ammonia, pH, and fecal coliforms. The oil and grease concentrations in the effluents from the plots were in most cases less than 5 mg/l, the limit of accuracy of the analytical method. The maximum value was 8.6 mg/l. Ammonia concentration averages ranged from 0.0 to 4.8 mg/l and maximum values ranged from 0.0 to 7.5 mg/l in the effluents from the plots. The pH levels ranged from 7.5 to 8.5 in the effluents. Additional data on these parameters are in the Appendix. Oil and grease, ammonia, and pH levels in the discharges meet both BPT and BAT

limits. The fecal coliform requirement for both limitations is a maximum of 400 mpn/100 ml. Maximum fecal coliform ranged from 8,000 to 320,000 mpn/100 ml in the discharges from the plots. The addition of disinfection facilities will enable the treatment systems to meet this limit.

DISCUSSION

These pilot investigations pointed out needed additions to the treatment system to meet BPT or BAT limitations. Disinfection is needed to meet the fecal coliform requirement in both limitations. Disinfection with chlorine is most economical with a chlorine contact basin having about a 1/2 hour detention. To meet BAT limits, the system also needs a means to control maximum daily discharge loads.

During two intense rainfalls when wastewaters were being applied, daily discharges in pounds of BOD and TSS were measured at ten times the average conditions and at five times the maximum daily limit. The increase in TSS caused the increase in BOD. The suspended solid limit was exceeded when the BOD limit was not exceeded. During these two rainfalls both volume and concentrations increased 2 to 5 fold over average conditions. During other rainstorms, however, discharge volumes were increased 2 to 5 fold over the average, but concentrations did not increase and the daily maximum limits were not exceeded. Although both volume and TSS concentration increased before the daily limits were exceeded, either or both can be controlled to meet the BAT limits.

There are a number of liquid-solid separation processes that can be used to reduce suspended solids. Most of these are physical-chemical processes which are mechanically complicated and expensive. Slow sand filtration is a simple process which might be employed. Its area requirements would be a 2 to 5% increase over that for the spray runoff plots. The spray runoff system can obtain 80 to 90 percent suspended

solids removal and is already available. Since raw wastewater would be sprayed during periods of plant operation, the irrigation system would be available at night and during weekends. However, storage facilities would be needed to use it during these periods.

Storage facilities offer several advantages. They can be designed with a maximum release to meet daily discharge limits. Reduction of suspended solids will occur through sedimentation. When concentrations of pollutants need additional reduction, part of the stored volume can be recycled. Storage facilities can be incorporated in the runoff collection system or can be created by damming natural depressions in the drainage system. Additional storage volume for chlorination can be incorporated at minimum cost. However, the permanent pool should be minimized to prevent algal growth. The storage facilities, like the irrigation plots, should be protected by diversion dikes from rainfall runoff from upslope areas.

The storage requirement would be dependent upon rainfall and temperature conditions and would vary from a few hours to several days. The storage volume would be controlled by the rainstorm selected for design. The data collected in this investigation were insufficient to determine the rainstorm which would result in the maximum waste load discharge. However, indications were that it would be a rainstorm over 0.7 inches. Storage of several times the runoff from a 0.7 inch rain would be a minor part of the total cost of the system.

For meatpackers in the northern part of the country, spraying of wastewater on land during extended periods of freezing weather would be physically impractical. Use of the runoff irrigation system would require storage during these periods.

Use of storage to control maximum daily discharges during heavy rainfalls and to stop application during extended periods of freezing weather suggests the potential for storage and flow equalization of the concentrated raw wastewater. Such storage could result in an anaerobic lagoon. The anaerobic lagoon, which can obtain over 80% BOD removal, is the most cost effective treatment process available to the meat industry.

The evaluation of treatment in an anaerobic lagoon followed by spray runoff irrigation was reported on previously (1). This investigation was carried out at these same facilities over a six month period ending in April 1972. Anaerobic effluent was applied at 8200 gal/acre/day which is within the range of hydraulic loadings used in this study. The BOD_5 loading was an order of magnitude less at 4.6 lb/acre/day, but the NH_3-N and T-P loadings were nearly double at 4.9 and 1.1 lb/acre/day, respectively. The runoff during the fall and winter study period averaged 56% of that applied. Removal efficiencies of both BOD_5 and TSS were in excess of 95%. Phosphorus removal was mainly dependent upon loss of flow.

A disadvantage of this system was the discharge of NH_3-N which averaged 20 mg/l and exceeded 10 mg/l in 85 percent of the observations. This was due to the high NH_3-N concentration in the anaerobic lagoon effluent which averaged 74 mg/l. The anaerobic lagoon converts most of the protein in meat packing wastewaters to ammonia. Thus, where ammonia limits exist, such as in BAT standards, storage in an anaerobic system is not advisable. In mild climates, storage facilities following the spray runoff irrigation system would eliminate the changes of anaerobic conditions and the resulting increase in ammonia. When storage of concentrated wastewater is required by cold weather, the wastewater can be kept aerobic by injection of air at the bottom of the storage facilities. Additional investigation of the spray runoff treatment system is needed to evaluate storage and application techniques.

Cost Estimates

The design and operational information developed in these pilot scale studies was used to make an estimate of cost. A number of assumptions were necessary; those most influencing costs were land prices, operational manpower, power requirements, repairs, and capital recovery. The costs were calculated for a system capable of treating 100,000 gallon/day. A medium size meat packing plant would have a flow of this magnitude or large

The screens were selected to handle a 175 gpm. The wet well was sized to equalize the output at 100 gpm. Three pumps each with a capacity of 50 gpm, were selected. The irrigation system was based on cost for similar systems used for crop production. Material quantities were determined from a layout sketch. Costs for pipe, automated valve, pumps, timers, and chlorination equipment were from catalogs and manufacturer quotes. The discharge storage facilities were sized for a 3 inch rainstorm and the recycle pump and line were sized for 50 gpm. Recycle pumping costs were based on 30 inches of rainfall.

The land requirement was based on a winter application of 6500 gpad. Land cost with clearing and grading was assumed at $1000/acre. Land and storage pond cost were amortized at 8% over 20 years. Equipment and structures were amortized at 8% over 10 years. Manpower estimates were based on 1 hour per day or per rainstorm and at $3.75 per hour. Thirty rainstorms per year were used. Electric power was estimated at 3¢ per KWH and was sufficient for pumping the wastewater and recycled flow against a 100 ft of head. Chlorine was priced at $13.50 cwt. Repairs plus taxes were estimated at 4.5% of capital cost per year. Table 5 shows a summary of the estimated costs.

Table 5. Annual Capital and Operating Cost Estimates

Item	Screening, Spray Irrigation & Chlorination		Storage & Recycle	
Land or Storage Pond	$1530		$205	
Equipment & Structures	2205		298	
Annual Capital Cost		$3735		$503
Manpower	$975		$112	
Electric Power	400		75	
Chlorine	90		--	
Repairs & Taxes	1350		180	
Annual Operation Cost		$2845		$367
Annual Capital & Operating		6580		870
($/1000 Gallon Treated)		$0.25		$0.03

Crites, et. al., (1) have reported capital costs for clearing of land, grading of slopes, planting and construction of the distribution system at $1,006 and $1,500 per acre for two overland flow systems. Operating costs for these two systems range from $0.05 to 0.10 per/1000 gallons. Land costs for eight other spray irrigation treatment systems ranged from $110 to $800 per acre.

Economic feasibility, especially for the small to medium packinghouse, is controlled by the cost of technical personnel for operation. Thus the limited mechanical equipment and automated operation of this process offer special cost advantages to these plants.

CONCLUSIONS

The restraints of the variables tested and of the test conditions necessarily qualify the following conclusions:

1. Treatment of meat packing wastewaters by screening, spray runoff irrigation, and disinfection can meet 1977 National discharge limitations.

2. Treatment of meatpacking wasteweters by screening, spray runoff irrigation, and disinfection can meet 30 day average limits in the 1983 National discharge limitations. Maximum daily limits for BOD_5 and suspended solids are exceeded when intense rainfall results in large increases in the discharge volume and concentration of suspended solids.

3. The spray runoff irrigation system removed over 90% of the total nitrogen applied and discharged an effluent with a maximum ammonia concentration of 4.5 mg/l. In the discharge, nitrate plus nitrite concentrations and temperatures had a significant correlation. Concentrations of all forms of nitrogen discharged noticeably decreased when effluent temperatures were 20°C or more.

4. The spray runoff irrigation system removed between 60 and 90% of the quantity of phosphorus applied. Removal was equal to the water lost to seepage and evaporation. Phosphorus concentrations decreased less than 10%.

5. The hydraulic and organic loadings had minor effects on removals.

6. Waste load discharges can be controlled by matching hydraulic loadings with weather conditions. For example: Loadings of 16,600 gpad in the summer and 6500 gpad in the winter resulted in the same waste load discharges which meet 1983 limits for BOD_5 and suspended solids. During hot weather loadings of 9000 gpad with water temperature at 19°C or of 10,500 gpad with water temperature at 25°C resulted in no surface discharge.

7. During periods when wastewaters are applied, rainfalls of greater than 0.7 inch/day can increase the waste load discharge to as much as ten times average conditions, exceeding the maximum daily valuc in the 1983 National discharge limitations. Between periods of wastewater application, rainfall can result in a waste discharge from the irrigation plots.

8. Control of the discharge in respect to volume and/or suspended solids concentration is necessary during intense rainfall to meet maximum daily limits in the 1983 National discharge limitations. Temporary storage facilities with a controlled discharge, and facilities for partial recycle to the irrigation area could offer this control at minimum cost.

9. Cost estimates for a 0.1 mgd plant including screens, wet well, spray runoff irrigation and chlorination were made from the design developed in this pilot scale study. Capital costs, including land, were $30,000. Annual capital and operating costs were $0.25/1000 gallons treated. The addition of a storage and recycle system would increase capital costs by $4,000, and annual capital and operating costs by $0.03/1000 gallons.

RECOMMENDATIONS

A full-scale system on the design and operation developed in this pilot scale study should be demonstrated in a warm climate. The system should include screens, spray runoff irrigation, and chlorination, followed by an auxiliary storage and recycling system to control discharges during rainstorms.

Further development of design and operation of this system should be undertaken in other parts of the country where extended freezing periods occur. The system should include screens, spray irrigation, chlorination and aerated storage. Pumps and pipes should be included for diverting flow both after screening and after irrigation to the storage facilities. This is to permit either control of the discharge during rainfall or of the land application during freezing weather.

ACKNOWLEDGEMENTS

This research project was a cooperative study by W. E. Reeves Packinghouse, East Central State University, Robert S. Kerr Environmental Research Laboratory, and the Pacific Northwest Environmental Research Laboratory. The project was supported in part by the U. S. Environmental Protection Agency under Grant No. 12060 GPP and Contract No. 68-03-0361.

Mr. W. E. Reeves, owner of the packinghouse, along with plant maintenance and operating personnel, constructed and maintained the treatment system. Mr. Jim Kingery, mathamatical statistician at the Kerr Laboratory, is given special acknowledgement for the data handling and statistical analyses. Michael Cook and Kenneth Jackson, chemistry technicians at this Laboratory, gave outstanding performance in their aid to packinghouse and university personnel in operating, sampling, and analytical quality control procedures. Dr. Ralph Ramsey and Mr. James Arnold, University personnel, handled plant operation, sample collection and weekly report preparation.

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APPENDIX - COMMON STATISTICS ON DATA BASE

Raw Wastewater - 74/01/09 to 74/06/18

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	24	22.08	6.85	32.00	10.00
LWK	lbs	24	32101.66	5363.97	41550.00	19980.00
Flow*	gpd	24	15710.83	2855.89	22180.00	10500.00
DO	mg/l	24	2.18	1.83	7.10	0.60
BOD_5	mg/l	22	634.18	199.85	1075.00	345.00
COD	mg/l	24	1675.29	438.79	3120.00	1044.00
pH		24	7.53	0.25	8.10	7.10
TS	mg/l	24	1970.66	279.88	2855.00	1526.00
TVS	mg/l	24	1075.79	292.77	2138.00	731.00
TSS	mg/l	24	498.62	256.60	1344.00	179.00
Set. S	ml/l	5	12.50	5.40	22.00	8.50
FOG	mg/l	5	139.40	116.88	343.80	56.20
NH_3-N	mg/l	22	13.42	5.61	29.30	6.00
NO_2+NO_3	mg/l	22	0.39	0.32	1.00	0.01
TKN	mg/l	24	87.88	19.73	128.40	57.05
T-P	mg/l	24	9.77	1.84	12.65	5.30
Fecal C	/100	4	2387500.	3888987.	8200000.	120000.

*Measurable flow was within a 12 hour period.

Spray Influents - 74/01/09 to 74/06/18

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	24	20.45	6.53	30.00	5.50
DO	mg/l	24	0.81	0.35	1.90	0.20
BOD_5	mg/l	21	374.66	105.63	530.00	180.00
COD	mg/l	24	960.37	244.73	1914.00	661.00
pH		24	7.37	0.15	7.75	7.10
TS	mg/l	24	1667.62	432.22	3504.00	1324.00
TVS	mg/l	24	649.75	158.27	1025.00	418.00
TSS	mg/l	23	218.82	85.04	378.00	92.00
Set. S.	ml/l	5	1.70	2.22	5.00	0.00
FOG	mg/l	5	67.46	61.15	139.90	14.70
Total N	mg/l	21	105.50	27.73	180.30	55.37
NH_3-N	mg/l	23	32.20	13.19	61.67	11.62
NO_2+NO_3	mg/l	22	0.43	0.64	3.20	0.02
TKN	mg/l	24	73.97	19.68	124.70	18.42
T-P	mg/l	24	7.23	2.42	12.40	2.90
Fecal C	/100	4	1487500.	1492411.	3700000.	450000.

Soil Plot No. 5 - 74/01/09 to 74/06/18

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	16	17.25	5.96	28.00	5.00
Flow On	gpad	21	10460.19	1587.67	13280.00	7314.00
Flow Off	gpad	21	2509.95	4320.53	13800.00	0.00
DO	mg/l	16	7.82	1.49	11.10	5.60
BOD5	mg/l	14	10.00	7.65	26.00	1.00
BOD On	#ad	19	32.66	11.32	51.32	16.16
BOD Off	#ad	14	0.41	0.75	2.71	0.00
BOD Off	#/LWK	14	0.01	0.03	0.14	0.00
COD	mg/l	16	123.31	34.28	194.00	82.00
COD On	#ad	21	81.23	19.69	128.70	44.50
COD Off	#ad	16	4.21	6.47	20.28	0.03
COD Off	#/LWK	16	0.20	0.35	1.08	0.00
pH		16	8.02	0.23	8.35	7.50
TS	mg/l	16	1350.75	256.03	2056.00	1007.00
TVS	mg/l	16	270.68	161.62	800.00	117.00
TSS	mg/l	16	25.18	21.43	86.00	5.00
Set. S.	ml/l	5	0.10	0.22	0.50	0.00
TSS On	#ad	21	17.82	7.08	33.75	8.34
TSS Off	#ad	16	1.04	2.30	8.99	0.00
TSS Off	#/LWK	16	0.05	0.12	0.48	0.00
FOG	mg/l	5	6.14	1.54	8.60	<5.00
T-N	mg/l	13	10.82	6.43	20.74	3.19
NH_3-N	mg/l	15	1.21	1.33	4.50	0.00
NH_3-N On	#ad	20	2.83	1.31	5.53	1.01
NH_3-N Off	#ad	15	0.04	0.08	0.28	0.00
NH_3-N Off	#/LWK	15	<0.01	0.00	0.01	0.00
NO_2+NO_3	mg/l	14	4.04	5.02	15.00	0.14
T-N On	#ad	18	9.42	2.99	16.19	3.72
T-N Off	#ad	13	0.35	0.53	1.71	0.00
TKN	mg/l	16	5.58	2.00	9.80	2.88
T-P	mg/l	16	6.75	1.53	10.80	4.35
T-P On	#ad	21	0.59	0.19	1.04	0.26
T-P Off	#ad	16	0.17	0.26	0.86	0.00
Fecal C	/100	4	100300.	149613.	320000.	1700.

gpad - gallons/acre/day

#ad - lbs/acre/day

#/LWK - Lbs/1000 lbs Live Weight Killed

/100 - most probably number /100 ml

Soil Plot No. 6a - 74/01/23 to 74/05/08

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	14	15.39	5.65	23.00	5.00
Flow On	gpad	15	9049.53	1086.39	10720.00	7487.00
Flow Off	gpad	14	4504.42	4190.85	14610.00	0.00
DO	mg/l	14	8.33	1.42	11.30	6.50
BOD_5	mg/l	14	5.84	6.07	25.00	0.80
BOD On	#ad	14	29.49	9.74	44.06	13.52
BOD Off	#ad	13	0.38	0.81	3.04	0.00
BOD Off	#/LWK	13	0.02	0.05	0.19	0.00
COD	mg/l	14	107.71	41.53	196.00	44.00
COD On	#ad	15	73.24	12.09	103.90	58.87
COD Off	#ad	13	5.09	6.45	23.87	0.52
COD Off	#/LWK	13	0.30	0.43	1.52	0.03
pH		14	8.03	0.19	8.40	7.60
TS	mg/l	14	1269.92	172.91	1512.00	946.00
TVS	mg/l	14	233.07	98.02	426.00	52.00
TSS	mg/l	14	23.85	20.42	65.00	2.00
Set. S.	ml/l	3	0.00	0.00	0.00	0.00
TSS On	#ad	14	14.35	4.45	20.43	7.26
TSS Off	#ad	13	1.01	1.78	5.35	0.07
TSS Off	#/LWK	13	0.06	0.12	0.34	0.00
FOG	mg/l	3	<5.00	0.00	<5.00	<5.00
T-N	mg/l	12	13.13	10.12	35.18	3.38
NH_3-N	mg/l	14	0.52	1.03	3.90	0.00
NH_3-N On	#ad	15	2.13	0.94	4.14	0.98
NH_3-N Off	#ad	13	0.02	0.05	0.17	0.00
NH_3-N Off	#/LWK	13	0.00	0.00	0.01	0.00
NO_2+NO_3	mg/l	12	8.67	9.88	31.20	0.18
T-N On	#ad	13	8.19	2.09	13.54	5.35
T-N Off	#ad	11	0.53	0.55	1.80	0.01
TKN	mg/l	14	4.20	1.98	9.40	1.10
T-P	mg/l	14	5.89	1.37	7.70	3.00
T-P On	#ad	15	0.5	0.22	1.07	0.24
T-P Off	#ad	13	0.23	0.21	0.77	0.02
Fecal C	/100	3	16300.	9130.	23000.	5900.

Soil Plot No. 6b - 74/05/15 to 74/06/18

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	5	27.40	3.13	30.00	22.00
Flow On	gpad	6	16613.33	1208.48	17390.00	14280.00
Flow Off	gpad	6	1119.41	1046.51	2588.00	0.00
DO	mg/l	5	6.78	1.07	8.40	5.60
BOD_5	mg/l	5	5.20	2.48	9.00	3.00
BOD On	#ad	6	47.74	15.49	72.51	32.76
BOD Off	#ad	5	0.06	0.07	0.19	0.01
BOD Off	#/LWK	5	0.00	0.00	0.00	0.00
COD	mg/l	5	103.20	17.93	118.00	77.00
COD On	#ad	6	110.90	25.13	142.10	90.72
COD Off	#ad	5	1.06	0.69	1.98	0.27
COD Off	/LWK	5	0.03	0.02	0.07	0.00
pH		5	8.30	0.14	8.50	8.10
TS	mg/l	5	1349.00	197.18	1587.00	1092.00
TVS	mg/l	5	179.40	33.41	222.00	142.00
TSS	mg/l	5	16.80	7.25	28.00	10.00
Set. S.	ml/l	1	0.00	0.00	0.00	0.00
TSS On	#ad	6	30.50	13.90	54.53	17.57
TSS Off	#ad	5	0.21	0.21	0.48	0.03
TSS Off	#/LWK	5	0.00	0.01	0.02	0.00
FOG	mg/l	1	<5.00	0.00	<5.00	<5.00
T-N	mg/l	5	3.05	0.47	3.54	2.45
NH_3-N	mg/l	5	0.00	0.00	0.00	0.00
NH_3-N On	#ad	6	5.82	1.65	8.94	4.17
NH_3-N Off	#ad	5	0.00	0.00	0.00	0.00
NH_3-N Off	#/LWK	5	0.00	0.00	0.00	0.00
NO_2+NO_3	mg/l	5	0.32	0.19	0.64	0.15
T-N On	#ad	6	14.57	5.09	22.10	7.59
T-N Off	#ad	5	0.03	0.02	0.07	0.00
TKN	mg/l	5	2.73	0.54	3.25	2.02
T-P	mg/l	5	6.91	0.62	7.40	5.94
T-P On	#ad	6	0.94	0.14	1.13	0.75
T-P Off	#ad	5	0.07	0.05	0.14	0.01
Fecal C	/100	1	8000.	0.00	8000.	8000.

Soil Plot No. 7a - 74/01/23 to 74/03/13

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	8	13.75	6.14	24.00	4.50
Flow On	gpad	8	6565.37	951.21	8085.00	5463.00
Flow Off	gpad	8	1154.50	826.72	2542.00	126.50
DO	mg/l	8	8.85	1.63	11.20	6.10
BOD_5	mg/l	8	6.00	2.72	12.00	3.00
BOD On	#ad	7	21.81	6.74	33.31	12.08
BOD Off	#ad	8	0.06	0.08	0.25	0.00
BOD Off	#/LWK	8	<0.01	0.00	0.01	0.00
COD	mg/l	8	103.25	36.52	176.00	69.00
COD On	#ad	8	52.77	11.37	76.23	38.27
COD Off	#ad	8	0.94	0.70	2.41	0.08
COD Off	#/LWK	8	0.06	0.04	0.15	0.00
pH		8	8.07	0.22	8.30	7.60
TS	mg/l	8	1252.87	171.90	1486.00	969.00
TVS	mg/l	8	271.50	182.61	694.00	110.00
TSS	mg/l	8	17.50	9.25	31.00	6.00
Set. So.	ml/l	2	0.00	0.00	0.00	0.00
TSS On	#ad	7	8.72	2.85	13.14	5.12
TSS Off	#ad	8	0.15	0.11	0.30	0.01
TSS Off	#/LWK	8	0.01	0.00	0.02	0.00
FOG	mg/l	2	<5.00	0.00	<5.00	<5.00
T-N	mg/l	7	15.97	7.78	25.76	5.15
NH_3-N	mg/l	8	0.63	0.77	2.17	0.00
NH_3-N On	#ad	8	1.13	0.33	1.63	0.64
NH_3-N Off	#ad	8	<0.01	0.01	0.04	0.00
NH_3-N Off	#/LWK	8	0.00	0.00	0.00	0.00
NO_2+NO_3	mg/l	7	11.05	7.66	22.00	0.65
T-N On	#ad	7	4.97	0.89	6.84	4.13
T-N Off	#ad	7	0.15	0.15	0.45	0.01
TKN	mg/l	8	4.26	1.26	7.00	2.70
T-P	mg/l	8	6.50	1.61	8.70	4.13
T-P On	#ad	8	0.48	0.11	0.66	0.31
T-P Off	#ad	8	0.06	0.04	0.12	0.00
Fecal C	/100	1	26000.	0.00	26000.	26000.

Soil Plot No. 7b - 74/03/20 to 74/06/18

Items	Units	No.	Mean	Stan. Dev.	Maximum	Minimum
Temp	Cent	14	22.92	6.13	30.00	9.00
Flow On	gpad	14	14794.28	360.78	15460.00	14350.00
Flow Off	gpad	14	4570.64	4949.43	17710.00	161.00
DO	mg/l	14	6.87	0.96	9.00	5.00
BOD_5	mg/l	13	10.15	13.48	53.00	2.00
BOD On	#ad	13	45.02	14.96	65.88	22.37
BOD Off	#ad	13	0.75	2.13	7.82	0.01
BOD Off	#/LWK	13	0.02	0.07	0.29	0.00
COD	mg/l	14	132.21	36.94	200.00	86.00
COD On	#ad	14	106.19	33.52	147.90	79.12
COD Off	#ad	14	5.25	7.45	28.65	0.26
COD Off	#/LWK	14	0.19	0.28	1.06	0.00
pH		14	8.05	0.27	8.60	7.60
TS	mg/l	14	1597.85	532.58	2700.00	1014.00
TVS	mg/l	14	215.92	99.32	490.00	122.00
TSS	mg/l	14	26.42	30.95	116.00	4.00
Set S.	ml/l	3	0.33	0.57	1.00	0.00
TSS On	#ad	14	27.97	8.61	46.74	15.32
TSS Off	#ad	14	1.12	2.83	10.93	0.06
TSS Off	#/LWK	14	0.04	0.10	0.40	0.00
FOG	mg/l	3	<5.00	0.00	<5.00	<5.00
T-N	mg/l	11	4.50	1.04	6.20	3.26
NH_3-N	mg/l	13	0.50	1.30	4.30	0.00
NH_3-N On	#ad	13	4.86	1.45	7.52	2.23
NH_3-N Off	#ad	13	0.04	0.10	0.34	0.00
NH_3-N Off	#/LWK	13	<0.01	0.00	0.01	0.00
NO_2+NO_3	mg/l	13	0.78	0.86	3.38	0.15
T-N On	#ad	12	14.25	3.98	22.41	6.62
T-N Off	#ad	11	0.14	0.18	0.53	0.00
TKN	mg/l	13	3.91	0.99	5.70	2.28
T-P	mg/l	14	6.47	1.60	9.20	4.80
T-P	#ad	14	0.71	0.18	0.96	0.35
T-P Off	#ad	14	0.21	0.21	0.72	0.01
Fecal C	/100	3	31133.	21703.	47000.	6400.